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MODIFIED FUNCTIONAL MOVEMENT SCREENING AS A PREDICTOR OF TACTICAL PERFORMANCE POTENTIAL IN RECREATIONALLY ACTIVE ADULTS

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ABSTRACT

Background: Failure to meet minimum performance standards is a leading cause of attrition from basic combat training. A standardized assessment such as the Functional Movement Screen™ (FMS™) could help identify movement behaviors relevant to physical performance in tactical occupations. Previous work has demonstrated only marginal association between FMS™ tests and performance outcomes, but adding a load challenge to this movement assessment may help highlight performance-limiting behaviors.

Purpose: The purposes of this investigation were to quantify the effect of load on FMS™ tests and determine the extent to which performance outcomes could be predicted using scores from both loaded and unloaded FMS™ conditions.

Study Design: Crossover Trial.

Methods: Thirteen female and six male recreationally active college students (21 ± 1.37 years, 168 ± 9.8 cm, 66 ± 12.25 kg) completed the FMS™ under (1) a control condition (FMS^{TM}_{C}), and (2) an 18.10kg weight vest condition (FMS^{TM}_{W}). Balance was assessed using a force plate in double-legged stance and tactical physical performance was evaluated via completion times in a battery of field tests. For each condition, penalized regression was used to select models from the seven FMS™ component tests to predict balance and performance outcomes. Data were collected during a single session lasting approximately three hours per participant. Results: For balance, significant predictors were identified from both conditions but primarily predicted poorer balance with increasing FMS™ scores. For tactical performance, models were retained almost exclusively from FMS^{TM}_{W} and generally predicted better performance with higher item scores.

Conclusions: The current results suggest that FMS™ screening with an external load could help predict performance relevant to tactical occupations. Sports medicine and fitness professionals interested in performance outcomes may consider assessing movement behaviors under a load.

Level of Evidence: 3

Keywords: Balance, movement quality, soldier athlete, talent identification

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INTRODUCTION

The Functional Movement Screen™ (FMS™) is a biomechanical assessment tool designed to identify movement limitations, as well as risk of injury, in clinical and field settings [1,2] A standardized test battery is applied to rate movement competency which may be related to deficits in these patterned functional movements. While it appears that the FMS™ is suitable for the purpose of predicting injury,[3] experimental findings thus far suggest that physical performance and movement competency as assessed by the FMS™ are at best weakly associated in most populations.[4-6] The screen has gained considerable popularity in competitive and recreational athletics,[7,8] as well as among tactical athletes such as military[3,9,10] and public safety professionals.[6,11] In addition to identifying individuals who may be at increased risk of injury, the FMS™ is also used as an indicator of performance and a means of guiding training interventions.[10] These latter applications are likely to become increasingly important in the coming years, particularly for the military, as substandard physical performance continues to be a risk factor for attrition in a quickly deteriorating recruitment environment.[12,13]

The modest findings with respect to FMS™ scores predicting physical performance likely stem from several factors. First, independently conducted factor analyses have concluded that it may be necessary to refine the way FMS™ scoring data is analyzed[14,15] Results from studies which have analyzed the composite score may not be valid as the underlying construct is not unidimensional.[14,15] Secondly, and more importantly, the FMS™ may not be sufficiently challenging to capture biomechanical differences which influence performance in physically rigorous activities. This is perhaps to be expected given that the screen was primarily intended to predict injury.[1,2] Recently, investigators have suggested that movement quality assessments might be more valid indicators of physical performance potential if they incorporated higher loads.[16] Under conditions of higher load, movement assessments could better approximate the levels of strength, balance, coordination, and range of motion characteristic of high-demand athletic activity. While the addition of a load may conflict with the generalist approach promoted by the FMS™, the authors of the current study emphasize that it should not be taken as such. The results of the assessment may still be interpreted to evaluate primitive and foundational movement behaviors as the authors suggest.[1,2,17] Further, these behaviors may be considered a reflection of biomechanical function, a general construct in which human performance and injury resilience are grounded. The utility of modifications such as applying an external load lie in their potential to highlight more clearly those deficiencies which could impact performance but are at the same time too subtle to be detected by a clinical instrument. Tactical occupations often require individuals to generate high forces, generate high forces quickly, cover distance quickly, and may involve manual material handling or load carriage. Use of external loading could help movement quality assessments such as the FMS™ to better approximate the physical demands of these occupations.

Therefore, the objectives for this investigation were 1) to quantify the effect of standardized loading on FMS™ scores in a recreationally active, young adult population, and 2) to determine the extent to which physical performance outcomes can be predicted by FMS™ scores obtained separately under a conventional condition and a weighted-vest condition. Outcomes included timed performance tests evaluating a range of physical performance attributes which have been implemented in previous investigations on tactical athletic performance.[18,19] The protocol also included force plate measures of standing balance. Balance has been shown to contribute to athletic performance[20] and is therefore included as an outcome in support of the second purpose of the study. In addition to its performance implications, balance data can be analyzed from a dynamical systems perspective and thereby provide insight into behavioral complexity.[21] Complexity outcomes should converge with FMS™ scores as separate indicators of biomechanical function. Additional analyses to test this theory were therefore included as an exploratory purpose of this investigation.

The following hypotheses were tested: 1) Item scores from the FMS™ administered with a weighted-vest (FMS^{TM}_{W}) would be lower than those from the conventionally administered FMS™ (FMS^{TM}_{C}). 2) Items from the FMS^{TM}_{W} condition would show greater predictive value than those from the FMS^{TM}_{C} condition with respect to timed physical performance tests. 3) Items from the FMS^{TM}_{W} condition would show greater predictive value than those from the FMS^{TM}_{C} condition with respect to standing balance.

METHODS

This study used a randomized crossover trial to investigate 1) within-subject differences in FMS™ item scores related to external loading, and 2) the predictive validity of FMS™ item scores from both conditions in predicting balance and tactical performance outcomes in a sample of recreationally active young adults. The project was approved by the Institutional Review Board at The University of North Carolina Greensboro and all data were collected by a single investigator in a controlled laboratory setting. A total of 19 subjects (13 females, 6 males; 21 ± 1.37 years, 168 ± 9.8 cm, 66 ± 12.25 kg) was recruited from the undergraduate population to participate in this investigation. All subjects were adults 18-34 years of age in order to simulate the range of ages for target recruitment populations in tactical occupations. Additionally, considering the physically intense nature of the protocol, participation was limited to subjects who indicated a minimum of 90 minutes/week of physical activity. All subjects completed a physical activity readiness questionnaire (PAR-Q) and signed informed, written consent prior to participation.

Procedures

All measurements were completed in one data collection session lasting approximately three hours. In order to prevent fatigue from influencing the more sensitive measures, balance and FMS™ testing were administered prior to the performance battery. Subjects were familiarized with all measures prior to data collection.

Balance testing was administered using a portable AMTI Accusway force plate and Balance Clinic software (AMTI Inc., Watertown, MA). Subjects stood barefoot for three 30-second trials of quiet, double-leg standing with eyes closed and hands on hips. Only the first of these three trials was analyzed in this study. Center of pressure (COP) coordinates were calculated from the raw force data sampled at 100Hz. Further analysis of COP time series was then conducted using custom programs written in LabVIEW 2012 (National Instruments, Austin, TX) using the entire 30-seconds of data for each participant.

In order to characterize different aspects of standing balance control, this investigation used both linear and nonlinear summary metrics. Mean COP velocity (COPV) was calculated in the antero-posterior (AP), medio-lateral (ML), and resultant directions. Sample entropy (SampEn) was then calculated on the COPV time series for each of these directions. SampEn is a nonlinear metric which is frequently applied as an indicator of complexity in biomechanical data. Constraints impinging on the balance system, such as sensory deficits or mechanical restrictions related to injury, are thought to limit the complexity of postural control behaviors. In addition to providing evidence of these constraints in clinical populations such as mTBI[22] and chronic ankle instability,[23] entropy measures have been shown to correlate with athletic skill.[21] The SampEn algorithm compares short template sequences of data points with subsequent vectors in the same time series in search of matches. Before doing so, two input parameters must be specified—an embedding dimension (m) and a radius (r). Respectively, m and r relate to the length of the template sequence to be matched and the error tolerance within which a match is counted. Previously published guidelines were used to optimize m and r with respect to the present dataset.[24] (Here, m = 2 and r = .07.) SampEn, then, is inversely related to the logarithm of the probability that a vector match identified at template length (m) will remain a match when length is incremented to ($m + 1$), not including cases in which the template is compared to itself.[25]

Following balance testing, subjects were assessed using The Functional Movement Screen™. The FMS™ consists of seven movement tests, each of which is scored from 0-3. In order, the movement tests are Deep Squat (DS), Hurdle Step (HS), Inline Lunge (ILL), Shoulder Mobility (SM), Active Straight Leg Raise (ASLR), Trunk Stability Push Up (TSPU), and Quadruped Rotary Stability (RS). Scores are assigned based on the following predetermined criteria: 3 = movement executed as prescribed, 2 = movement executed with modification or imperfection, 1 = movement not executed. A "0" is assigned to any test that elicits pain, regardless of the subject's performance.

The FMS™ was administered under two conditions—once without additional weight (FMS^{TM}_{C}) and once while wearing an adjustable 18.10 kg (39.90 lbs.) weight vest (FMS^{TM}_{W}) (MiR Vest Inc., San Jose, CA). All FMS™ testing was conducted by a single, experienced rater. A recently developed movement screen suggested for use in athletic populations, the Athletic Ability Assessment (AAA), incorporates loads of 10 kg (22.05 lbs.) and 20 kg (44.09 lbs.) in the form of barbells.[16] Thus, the weight vest treatment in this study used a load within the range of those used in the AAA. The order of the conditions was randomized so as to prevent practice effects from disproportionately affecting either condition.

Next, participants completed a standardized stationary bicycle warm-up and began a battery of physical performance tests. These tests were based on previous research evaluating tactical performance[18,19] and included, in order, a series of five 27.43 meter (30 yards) sprints, a 400 meter run, a military-specific mobility test (the Mobility for Battle Assessment[18]), and a partner rescue simulation. Subjects were instructed to complete each individual test as quickly possible. Completion times were recorded using a timing device (Brower Timing Systems, Draper, UT) with a start-on-release trigger mechanism and photocell to record start and stop times, respectively.

Subjects completed the five sprint trials with a maximum of 60 seconds of rest between efforts. After recovering from the final sprint trial, all subjects completed a single 400 meter run and were then permitted to rest as needed before proceeding to the Mobility for Battle Assessment (described in the following paragraph). Subjects began the sprint and 400 meter events with one foot depressing the start-on-release trigger and began each trial following a countdown of "3-2-1-Go." Finish times were recorded using the timing system photocell. The sprint times used for statistical analysis represent an average of all trials for each subject.

The Mobility for Battle assessment incorporates a broad range of physical demands which may be encountered in combat environments.[18] The entire assessment is completed in a single effort as quickly as possible and includes: shuttle runs, push ups, bear crawls, broad jumps, water-can carries (using equivalent weight in the present study), and Russian twists performed with an 8.16 kg (18 lbs.) medicine ball. Before beginning the test, each subject received a thorough description and demonstration of all tasks. Additional verbal cues were provided during live test administration prior to the subjects' arrival at each substation. Subjects were then permitted to rest as needed before beginning the final test, the partner rescue simulation.

For the partner rescue simulation, three 50lbs sandbags were fastened together using nylon rope and then reinforced with duct tape. Subjects were required to drag the load 50 yards across the gym floor as quickly as possible following the "go" command. Completion time was recorded when the final bag crossed the finish line.

Statistical Analyses

The *a priori* significance level for all analyses was set at $p < 0.05$. Item scores from the weighted and control conditions were compared directly using one-tailed Wilcoxon signed rank tests for matched pairs.

It has recently been demonstrated that the FMS™ lacks the psychometric properties necessary for making the composite score a meaningful summary.[14,15] Therefore, a more appropriate analysis is to use the constituent items of the screen in a multiple regression model. However, doing so is not without challenges. First, the number of predictors is vastly increased. Second, the FMS™ item scores contain ordinal level data. Regression procedures designed for nominal and/or continuous predictors both have disadvantages when applied to ordinal independent variables. These include dummy coding models, in which model fit may be overestimated, as well as linear models, which suffer from the additional limitation that the continuous scaling is artificial.[26] Therefore, in order to address the research questions in the present study, the authors applied recently developed regression techniques which enable valid model selection and can account for ordinal scaling within the predictor variables using a data-driven penalty parameter. Penalized regression typically minimizes the sum of squared errors subject to a constraint on the sum, or squared sum, of the coefficient terms. This discourages high coefficient values, which are more likely to be specific to a particularly sample of the data. Penalized regression has the advantage of optimizing the bias-variance tradeoff and can be particularly useful in cases involving a large number of predictors and/or small sample sizes.

For both the weighted and control conditions, regression models were constructed using FMS™ test items as predictors. Each FMS™ test item is considered to be a separate factor consisting of grouped covariates which are represented by the levels (scores of 1, 2, or 3) within a factor. The first step was to identify a model at the factor level using the group Lasso algorithm, which penalizes groups of coefficients rather than individual coefficients. Models were selected according to the penalty parameter lambda (Λ) which minimized cross validation error in the group Lasso solution. The factors retained in the solution were then smoothed across levels using the same penalty term. Like other dummy coding regression procedures, one level of the independent variable must be designated to serve as a reference category for estimated changes in the outcome as the levels of the predictor increase. For the present investigation, the level corresponding to an FMS™ score of "1" was used as the reference category and is therefore assigned a zero dummy coefficient. Significance was tested using bootstrap (BCa method) 95% confidence intervals for each dummy coefficient retained in the final models. All computations were conducted in R 3.1.0 using the ordPens[26,27] (version 0.2-.1), grpreg[28] (version 2.6-0), boot[29] (version 1.3-11), and base packages.

Table 1. *Group penalization parameters (Λ) based on minimum cross-validation error along with the number of features retained for each model using both weighted and control FMS™ scores*

Test	FMS_C		FMS_W	
	Λ	*Features*	Λ	*Features*
Sprint	0.15	1	0.13	1
400	9.08	0	0.98	6
Agility	5.68	0	2.68	5
RSQ	4.01	0	2.88	3
APV	0.04	4	0.04	4

FMS^{TM}_C = FMS™ control condition, FMS^{TM}_W = FMS™ weighted condition.

RESULTS

Table 1 summarizes the penalty parameters that were applied to each penalized regression model. Results of the Wilcoxon signed rank tests are presented in Table 2 and show significant decreases in the FMS™ scores during the weighted condition for the Shoulder Mobility, Active Straight Leg Raise, Trunk Stability Push Up, and Rotary Stability tests. Finally, regression models are summarized in Tables 3-5, which show bootstrap 95% confidence intervals and smoothed dummy coefficients for performance and balance outcomes. For the sake of comparison, non-smoothed results are presented as well. With the exception of the partner rescue simulation, for which $n = 16$, data for all 19 subjects were used for each analysis.

Because lower completion times reflect better performance in the timed tests, a negative relationship indicates superior performance as FMS™ item scores increase. For the FMS^{TM}_C condition, the only factor retained in the performance prediction models was TSPU, in which a score of 3 was predictive of faster sprint speed. Models using the FMS^{TM}_W item scores retained a greater number of factors than their FMS^{TM}_C equivalents. A 3 in the TSPU for the FMS^{TM}_W condition was predictive of faster completion in all of the timed tests. Also in the FMS^{TM}_W condition, a score of 3 on the DS and a score of 2 on the HS were predictive of faster completion of the 400 m

Table 2. *Wilcoxon signed rank tests correspond to the null hypothesis that FMS^{TM}_C item scores = FMS^{TM}_W item scores. The alternative hypothesis was that FMS^{TM}_W item scores < FMS^{TM}_C item scores. P-values are not exact as at least one tie was observed for each comparison*

Condition	Score	Item						
		DS	HS	ILL	SM	ASLR	TSPU	RS
FMS_C	1	6	3	2	1	0	4	9
	2	12	15	14	2	4	7	7
	3	1	1	3	16	15	8	3
FMS_W	1	10	4	7	3	2	10	11
	2	8	14	10	14	8	2	8
	3	1	1	2	2	9	7	0
Results	V	17.5	9	49.5	136	36	21	10
	p	0.06	0.38	0.06	0.01*	0.01*	0.01*	0.04*

FMS^{TM}_C = FMS™ control condition, FMS^{TM}_W = FMS™ weighted condition.
*Indicates statistically significant differences.

Table 3. *Dummy coefficients, both before and after applying the smoothing algorithm, and 95% bootstrap confidence limits for FMS™$_C$ and FMS™$_W$ test items retained for the prediction of sprint and 400 meter times. Reference category coefficients (corresponding to FMS™ score = 1) are not shown*

		No Weight		Weight		No Weight		Weight	
	Level	Coef	95% CI	Coef	95% CI	Coef	95% CI	Coef	95% CI
		Sprint (Smoothed)				Sprint (Unsmoothed)			
TSPU	2	-0.24	(-0.69, 0.15)	0.02	(-0.40, 0.36)	-0.24	(-0.71, 0.16)	0.05	(-0.40, 0.41)
	3	-0.78	(-1.26, -0.15)*	-0.82	(-1.15, -0.25)*	-0.79	(-1.27, -0.15)*	-0.82	(-1.15, -0.26)*
		400 meter (Smoothed)				400 meter (Unsmoothed)			
DS	2	--	--	-15.35	(-24.54, 2.36)	--	--	-18.92	(-32.10, 152.06)
	3	--	--	-22.02	(-36.18, -9.86)*	--	--	-21.79	(-62.65, 13.02)
HS	2	--	--	-13.67	(-44.57, -0.55)*	--	--	-16.47	(-93.88, 22.51)
	3	--	--	-11.99	(-39.11, 3.38)	--	--	-10.24	(-72.45, 60.25)
ILL	2	--	--	2.12	(-12.69, 11.06)	--	--	1.88	(-30.47, 49.70)
	3	--	--	12.79	(-5.43, 28.79)	--	--	15.09	(-19.96, 66.47)
SM	2	--	--	6.67	(-3.83, 21.86)	--	--	9.07	(-84.58, 45.65)
	3	--	--	22.85	(-1.84, 48.55)	--	--	27.23	(-75.44, 73.75)
TSPU	2	--	--	-9.51	(-29.24, 1.58)	--	--	-10.57	(-66.11, 59.62)
	3	--	--	-20.24	(-36.87, -6.81)*	--	--	-22.56	(-48.05, 50.91)
RS	2	--	--	-4.20	(-23.68, 8.40)	--	--	-4.09	(-48.29, 26.37)
	3	--	--	-4.20	(-23.68, 8.40)	--	--	-4.09	(-48.29, 26.37)

FMS™$_C$ = FMS™ control condition, FMS™$_W$ = FMS™ weighted condition, DS = Deep Squat, HS = Hurdle Step, ILL = Inline Lunge, SM = Shoulder Mobility, TSPU = Trunk Stability Push Up, RS = Rotary Stability. *Indicates statistically significant differences.

run. DS and HS in the FMS™$_W$ condition were similarly predictive of faster completion of the Mobility for Battle course, in this case with scores of either 2 or 3. Finally, scoring a 3 in the SM or ILL in the FMS™$_W$ condition was predictive of *slower* completion of the partner rescue task.

With respect to the balance outcomes, the only measure for which any factors were retained in the group lasso solution was mean APCOPV. In the FMS™$_C$ condition, a DS score of 2 or 3 was predictive of greater APCOPV. In the FMS™$_W$ condition, scores of 3 on the DS and ILL were predictive of greater APCOPV. Lower mean COPV values are interpreted to reflect better postural control.

DISCUSSION

The most important finding of this investigation is that the relationship between FMS™ test items and physical performance appears to be more consistent with the underlying theory of the FMS™ when the battery is performed under load. This may lend support to the practice of screening movement quality for its potential impact on performance, but might also suggest that more demanding conditions are required before performance-relevant differences in movement behaviors can be observed. Based on the current findings, it appears that a conventionally administered FMS™ is not sufficiently challenging to identify movement deviations that could affect performance relevant to tactical occupations. An increased load is just one method that could be used to address this shortcoming. As alternatives, the screen might have been administered at high speed or following a fatigue protocol to assess movement quality under other conditions one might face in training or on the job. The ability to predict performance and identify performance-limiting behaviors on which to intervene is important, especially considering the challenges facing military recruitment efforts.[12,13] Performance failure is a major factor in attrition and washback;[30] however, excessively high injury rates suggest that increases in training volume and intensity may not be the appropriate solution. Targeted selection and remediation, each of which could benefit from cost-effective clinical screens, may be a more viable approach.[13]

Several authors have published studies that investigate the relationship between physical performance

Table 4. *Dummy coefficients, both before and after applying the smoothing algorithm, and 95% bootstrap confidence limits for FMS™$_C$ and FMS™$_W$ test items retained for the prediction of Mobility for Battle and simulated partner rescue times. Reference category coefficients (corresponding to FMS™ score = 1) are not shown*

		No Weight		Weight		No Weight		Weight	
	Level	Coef	95% CI	Coef	95% CI	Coef	95% CI	Coef	95% CI
		Mobility for Battle (Smoothed)				Mobility for Battle (Unsmoothed)			
DS	2	--	--	-11.23	(-22.08, -1.73)*	--	--	-18.05	(-47.53, 4.08)
	3	--	--	-19.59	(-41.38, -8.79)*	--	--	-17.78	(-62.01, 3.77)
HS	2	--	--	-12.09	(-29.37, -1.86)*	--	--	-14.15	(-38.44, 31.94)
	3	--	--	-17.15	(-38.22, -4.96)*	--	--	-4.49	(-31.00, 84.50)
ILL	2	--	--	7.06	(-4.53, 18.68)	--	--	9.14	(-21.64, 33.42)
	3	--	--	19.30	(-1.84, 46.10)	--	--	29.99	(-3.86, 94.74)
TSPU	2	--	--	0.48	(-9.47, 13.30)	--	--	16.44	(-10.14, 105.53)
	3	--	--	-22.40	(-35.85, -5.46)*	--	--	-32.07	(-59.63, 12.37)
RS	2	--	--	-6.42	(-20.25, 3.78)	--	--	-11.56	(-43.49, 7.87)
	3	--	--	-6.42	(-20.25, 3.78)	--	--	-11.56	(-43.49, 7.87)
		Partner Rescue (Smoothed)				Partner Rescue (Unsmoothed)			
DS	2	--	--	-4.36	(-10.25, 1.09)	--	--	--	--
	3	--	--	-0.29	(-6.65, 5.88)	--	--	--	--
ILL	2	--	--	2.42	(-4.44, 7.49)	--	--	5.99	(1.10, 18.32)*
	3	--	--	13.25	(9.64, 19.33)*	--	--	22.83	(16.64, 44.85)*
SM	2	--	--	5.05	(-0.36, 11.88)	--	--	4.69	(-2.04, 20.33)
	3	--	--	9.46	(5.28, 19.55)*	--	--	9.09	(-0.14, 23.54)
TSPU	2	--	--	-1.05	(-8.46, 4.76)	--	--	14.68	(-7.06, 27.73)
	3	--	--	-11.09	(-16.91, -4.23)*	--	--	-14.66	(-25.99, -7.06)*

FMS™$_C$ = FMS™ control condition, FMS™$_W$ = FMS™ weighted condition, DS = Deep Squat, HS = Hurdle Step, ILL = Inline Lunge, SM = Shoulder Mobility, TSPU = Trunk Stability Push Up, RS = Rotary Stability. *Indicates statistically significant differences.

and FMS™ scores.[5,6,31,32] Whether considering the total score or individual item scores, the relationships identified in these previous investigations have been inconsistent. One study conducted in a sample of NCAA football players found relationships between FMS™ composite scores and squat strength, power clean strength, 40 yard dash time, shuttle run time, and vertical jump height.[31] These findings, while impressive, may not generalize to all populations. Other FMS™ research has found weak, if any, associations with performance outcomes in non-football collegiate athletes,[5] as well as tactical populations.[6,32] Notably, the authors of one of the latter studies[6] commented that load may affect movement quality and suggest that evaluating movement behaviors under varying loads and speeds might strengthen their relationship with performance outcomes. To date, this is the first investigation to administer the FMS™ under a weighted condition and examine its relationship to criterion performance tasks. While the literature suggests that movement quality as measured by the FMS™ may not relate to fundamental behaviors which impact performance across a variety of domains, the present findings indicate that movement screens can provide useful information when modified such that the test more closely approximates the requirements of high-performance efforts.

The relevance of the FMS™ tasks to general and fundamental biomechanical function might be

Table 5. *Dummy coefficients, both before and after applying the smoothing algorithm, and 95% bootstrap confidence limits for FMS™$_c$ and FMS™$_w$ test items retained for the prediction of balance outcomes. Reference category coefficients (corresponding to FMS™ score = 1) are not shown*

		No Weight		Weight		No Weight		Weight	
	Level	Coef	95% CI	Coef	95% CI	Coef	95% CI	Coef	95% CI
		APCOPV (Smoothed)				APCOPV (Unsmoothed)			
DS	2	0.22	(0.23, 0.41)*	0.10	(-0.03, 0.39)	0.22	(0.23, 0.41)*	0.10	(-0.03, 0.41)
	3	0.55	(0.58, 0.77)*	0.42	(0.27, 0.77)*	0.56	(0.59, 0.76)*	0.43	(0.25, 0.78)*
HS	2	0.13	(-0.02, 0.43)	--	--	0.13	(0.00, 0.52)*	--	--
	3	-0.19	(-0.73, 0.08)	--	--	-0.19	(-0.74, 0.07)	--	--
ILL	2	--	--	0.09	(-0.04, 0.38)	--	--	0.09	(-0.04, 0.38)
	3	--	--	0.20	(0.03, 0.72)*	--	--	0.20	(0.04, 0.65)*
SM	2	-0.03	(-0.65, 0.42)	--	--	-0.03	(-0.64, 0.42)	--	--
	3	-0.03	(-0.61, 0.30)	--	--	-0.03	(-0.62, 0.30)	--	--
ASLR	2	0.00	(0.00, 0.00)	-0.17	(-0.87, 0.06)	0.00	(0.00, 0.00)	-0.17	(-0.83, 0.07)
	3	-0.08	(-0.40, 0.09)	-0.19	(-0.87, 0.04)	-0.08	(-0.42, 0.09)	-0.19	(-0.84, 0.03)
TSPU	2	--	--	0.04	(-0.28, 0.47)	--	--	0.04	(-0.26, 0.50)
	3	--	--	0.06	(-0.11, 0.37)	--	--	0.06	(-0.12, 0.37)

FMS™$_C$ = FMS™ control condition, FMS™$_W$ = FMS™ weighted condition, APCOPV = Antero-posterior center of pressure velocity, DS = Deep Squat, HS = Hurdle Step, ILL = Inline Lunge, SM = Shoulder Mobility, ASLR = Active Straight Leg Raise, TSPU = Trunk Stability Push Up. *Indicates statistically significant differences.

called into question by the unexpected findings with respect to postural control. Balance and FMS™ item scores were generally unrelated in this study. Mean APCOPV was the only balance outcome retained in any model and, unexpectedly, predicted poorer balance as FMS™ item scores increased. There is little in the way of published research on FMS™ and static balance control. One investigation exploring the impact of fatigue in these variables identified a negative relationship between baseline HS and COP standard deviation.[33] Another study focusing specifically on the ILL task found that it was unrelated to COP excursion.[34] While the evidence is scarce, one would expect to observe different indicators of biomechanical function to demonstrate a positive relationship, if any. It is not clear why the results in the current study would follow this counterintuitive pattern. One possibility is that subtle differences in biomechanical function are obscured by the low-resolution clinical scoring criteria. Alternatively, it may be the case that biomechanical function as assessed by FMS™ movement skills is not the same as that indexed by force plate measures.

The current study also attempts to address concerns regarding the psychometric properties of the FMS™ and other assessments, which may use similar scoring practices. Much of the appeal of the FMS™ draws from its clinical applicability and evidence supporting the use of cutoff points for composite scores to indicate risk of future injury.[3,9] Previous investigations have treated composite scores as interval level data,[8,10,11] which is arguably artificial given the ordinal nature of its constituents. Regardless of how the composite score is treated, the underlying factor structure and lack of internal consistency among the test items suggest that combining their scores is inappropriate.[14,15] The task then becomes analyzing the item scores themselves, which are unambiguously ordinal. It can be said, for example, that a "3" is better than a "2," but not that the difference between scores "1" and "2" is equal to the difference between scores "2" and "3". The smoothing process applied in the current analysis allows more information to be captured in the model than would be possible through standard dummy coding techniques. Particularly in the timed performance tests, the confidence intervals are considerably narrower for the smoothed results. In several cases, this leads to a significant finding where more traditional procedures would not. Simulation studies have demonstrated that the approach used in this investigation outperforms the more traditional approaches while simultaneously avoiding problems associated with over- or underfitting.[26] The benefits of this method could extend to other models for predicting success in incoming military recruits, many of which are based on likert-type survey responses.[35]

Several limitations should be noted with respect to this investigation. First, the load used in the FMS™$_W$ condition was not adjusted according to a participant's size or strength. While this limits the authors' ability to discuss the mechanism by which the weight vest affected scores across individuals, this research intentionally examined within-subjects effects using a load treatment similar to that employed in previous research.[16] Second, while the primary interest of the study was to determine the effect of standardized load, it was difficult to control for mechanical restriction in all subjects, particularly in the SM task. Third, the authors' note that this investigation was conducted in a controlled laboratory setting which may limit the extent to which the findings can be generalized to tactical environments. Finally, the analyses considered men and women together. Further research will be required to establish whether these effects are sex-specific.

CONCLUSIONS

Several conclusions may be drawn from the current results. These data indicate that movement function as assessed by the FMS™ deteriorates with increased load. Further, movement behaviors observed under the more challenging external load condition may be better predictors of performance outcomes. At the same time, an unexpected relationship was observed between postural control and FMS™ movement behaviors in both conditions. These results support using movement screening as a predictor of physical performance, but failed to support the original interpretation of FMS™ movement behaviors as fundamental to a range of human activities.[17] Specifically, results of the balance analyses could not confirm that movement quality reflects foundational aspects of biomechanical function relevant to different types of behaviors. Future studies should seek to separate the effects of movement quality on performance outcomes from the effects of other factors which have previously been understood to reflect independent components of fitness.

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